Erasable Patterning using Smectic Layer Rotation by Optical Heating

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Ferroelectric liquid crystals (FLCs) have attractive properties for electro-optical applications such as a fast response caused by the direct interaction between the spontaneous polarization (Ps) and an electric field, and a bistability in a thin cell. Therefore, electro-optical devices using FLCs having a memory function have been extensively studied. Most devices have, naturally, used this bistability to realize a memory function, that is, the surface-stabilized ferroelectric liquid crystal (SSFLC). So, a dynamics of molecular switching have been mainly researched in the application field of FLCs. However, we have researched a dynamics of the smectic layer. Firstly, we have reported the smectic layer rotation induced by application of asymmetric voltage pulses in chiral smectic liquid crystals [1-3]. This layer rotation is continuously and reversible. We reported the idea of the optical device using this properties and the change of the optical response by the layer rotation [4]. Nevertheless, the device cannot handle a spatial pattern, since the whole layer in the cell uniformly rotates. Because the layer rotation involves fundamental and practical subjects, other researchers have researched the reorientation of the smectic layer also [5-7]. Secondly, we have proposed a novel optical recording, in which a pattern was stored as an alignment of the smectic layer structure [8-10]. An essential idea was the use of the property of FLC having a chiral nematic (N*) – chiral smectic C (SmC*) phase sequence. In the rubbing cells using this FLC, two domains with different layer alignments coexist in the SmC* phase. For realizing the optical patterning, the use of the phase transition induced by optical heating [8, 9] and the photoisomerization [10] were proposed. Depending on the mechanism using only two types of the layer alignments, these patterning methods can store only a binary spatial pattern.

In this study, we propose the novel optical patterning using the smectic layer rotation. We can use the continuous countless layer alignments controllable by application of asymmetric voltage pulses, though only two types of layer alignments in FLC with the N* – SmC* phase transition. This indicates that this patterning has a memory function of a multi-level spatial pattern. In order to realize the optical patterning, the temperature dependence of the layer rotation rate was used.

A FLC used in this study was CS-1024 (Chisso) with Isotropic – N* – smectic A (SmA) – SmC* phase sequence. In the optical patterning experiments, G-239 (Hayashibara biochemical laboratories) dye was doped into the FLC in 1.3 wt% concentration to improve the efficiency of the laser absorption. The cell used in this study was commercial one (E. H. C.). The cell consisted of two indium-tin-oxide (ITO)-coated glass plates and the cell gap was 10 μm. The surfaces of two glass plates were coated with a rubbed polyimide layer and the rubbing directions were in the antiparallel direction. The temperature of the cell was controlled using a hot bath and a temperature controller (Shimaden, FP21). Applied voltage pulses were generated by an arbitrary waveform generator (Agilent, 33120A) and were amplified by a voltage amplifier (FLC Electronics, F20A). A polarizing optical microscope (Nikon, Eclipse E600) was used for the microscope observation. The microphotographs were taken by a digital camera (Nikon, Coolpix 950). A diode-pumped crystal laser (CrystaLaser, GCL-100-S) was used as a light source. The wavelength, the output power and the transverse mode of the laser were 532 nm, 100 mW and TEM_{00}, respectively.

Because the method proposed in this study uses the temperature dependence of the rotation rate, it was investigated so as to optimize the operating temperature. The rotation rate was defined as the average of the rotation angle per asymmetric pulse at application of 100 pulses. The pure CS-1024 was used. A sawtooth waveform, whose amplitude voltage and frequency were ±50 V and 3 Hz respectively, was used as an asymmetric voltage pulse, as shown in Fig. 1. Figure 2 shows the rotation rate as a function of the reduced temperature with the transition temperature $T_{A\text{-}C}$ from the SmA to the SmC* phase. This result shows that the rotation rate sensitively depends not only on the temperature in the SmC* phase, but also on the phases. The rotation rate in the SmA phase was extremely smaller than that in the SmC* phase. (As reported in ref. [3], the significant layer rotation was caused by application of asymmetric voltage pulses with adequate amplitude in the SmA phase.) Consequently, the most efficient way to apply the temperature dependence is to use the change of the rotation rate by the phase transition.

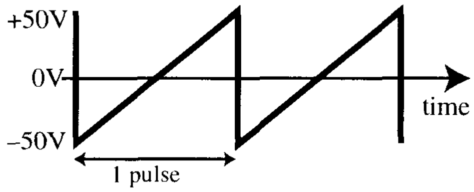

Fig. 1. Asymmetric voltage pulses in this study.

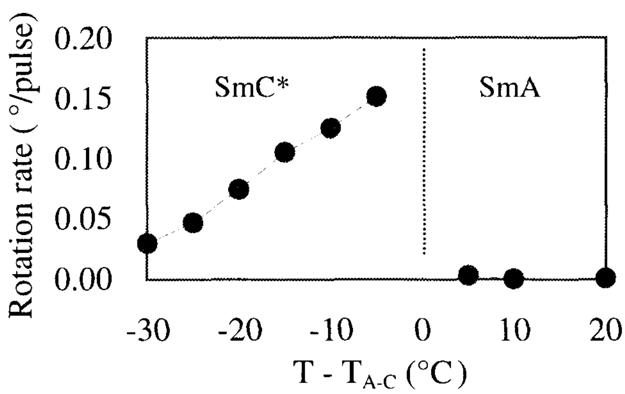

Fig. 2. Rotation rate as a function of the temperature.

The following process is proposed on the basis of the above result. The temperature of the cell is kept just below $T_{A\text{-}C}$ in the SmC* phase. When the laser beam is irradiated to part of the cell, only the sample in the irradiated area becomes the SmA phase by optical heating (Fig. 3 (a)). Here, the sample in the irradiated area does not show the layer rotation under application of asymmetric voltage pulses, while the sample in the other area, which remains in the SmC* phase, shows the layer rotation. Therefore, the application of asymmetric voltage pulses during the laser irradiation results in a change of the layer alignment only in the irradiated area, as shown in Fig. 3 (b). Under applying a dc field, the directions of the optical axes in each area are different, since the molecules tilt in the specific direction with respect to the layer normal. Accordingly, the difference of the layer alignments can be converted into that of the optical intensity using polarizers. In addition, the stored pattern can be erased in the similar way owing to the reversible property of the layer rotation. As shown in Figs. 3 (c) and (d), if the asymmetric voltage pulses with the opposite polarity are used, the layer in the non-irradiated area rotates in the opposite direction to the case in the writing process (Figs. 3(a), (b)). As a result, the layer alignment becomes the initial state as shown in Figs. 3 (d).

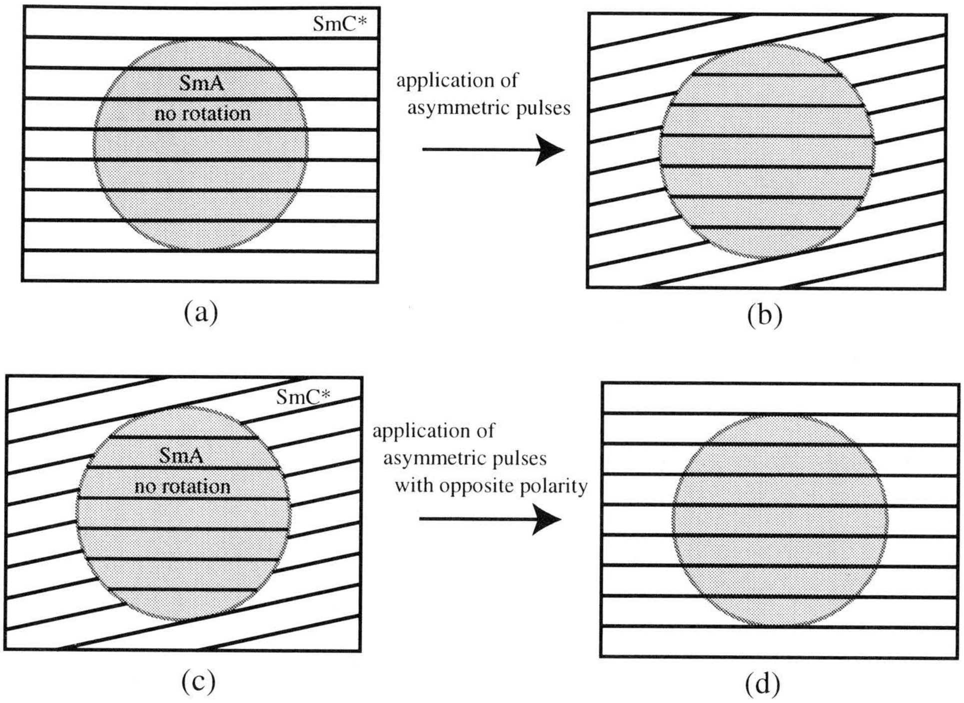

Fig. 3.　Schematics of optical patterning proposed in this study.
(a), (b) Writing process.　　(c), (d) Erasing process.

Next, we show the experimental results of the proposed optical patterning. The FLC doped with G-239 was used. In this experiment, the cell was kept at 1 °C below $T_{A\text{-}C}$. The power of the incident laser beam into the cell was reduced to 50 mW with a neutral density filter. The profile of the laser beam through a mask was a rectangle on the sample, though that of the original laser beam was a circle with a diameter of 2.3 mm. The amplitude and the frequency of the used sawtooth pulses were ±50 V and 5 Hz respectively. The number of applied pulses was 50 in the writing process and 25 in the erasing process. This is because the rotation rate depends on the rotation direction in the case of a rubbing cell. Figure 4 (a) shows a polarizing microphotograph after the writing process, which corresponds to the step of Fig. 3 (b). The dark domain is the irradiated area, that is, the layer alignment in this area was not changed by application of asymmetric voltage pulses. On the contrary, the layer rotation was induced in the bright area in Fig. 4 (a). Subsequently, the erasing process was performed and the results is shown in Fig. 4 (b). The whole area looks uniform and this indicates that the layer alignment returned to the initial state.

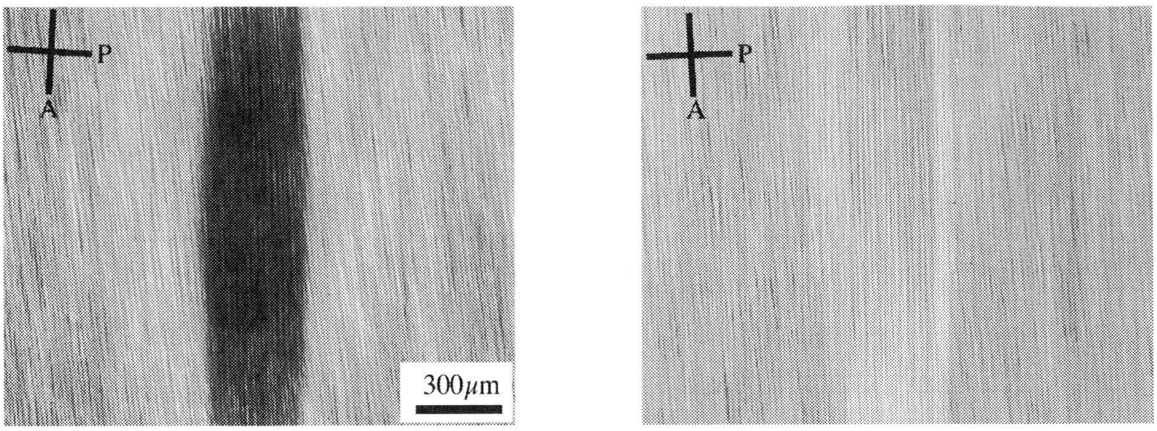

Fig. 4. Polarizing microphotographs with an applied dc voltage of 20V.
(a) After the writing process. (b) After the erasing process.

Finally, we notice the merits in this method. The inverted pattern of the stored pattern can be obtained fast and easily by changing the polarity of the applied dc field to read the stored pattern. Furthermore, the multi-level pattern can be handled, since the used layer rotation phenomenon shows the continuously rotation of the layer alignment.

In conclusion, we proposed and demonstrated the novel optical patterning in FLC using the smectic layer rotation induced by application of asymmetric voltage pulses. This patterning has the ability to handle a multi-level pattern, and the functions of erasing and inversion of the stored pattern. This optical patterning can be applied to electro-optical devices such as image memory, functional spatial light modulator and so on.

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